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Determination of the Storage Volume in Rainwater Harvesting Building Systems: Incorporation of Economic Variable

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1. Introduction

Rainwater harvesting has been used as a technique to promote water conservation in buildings, as it substitutes the potable water in activities where the use of potable water is not required.

In spite of the surge in interest over recent years, some questions still remain regarding to these systems, mainly what involves the reservoir sizing. There are many methods for this purpose that use different inputs such as: rainwater demand, catchment area, roof material, rainy data (daily or monthly) and dry periods. Even in the Brazilian Standard (ABNT, 2007), there is no consensus as to which method should be used. Table 1 shows the main methods found in the literature and their respective inputs.

Mainly in developing countries, actions that promote water conservation must be economically feasible so it can raise the interest in investments. Moreover, urban lots are progressively smaller and more expensive. These variables can restrict the size of the reservoirs used in a rainwater system and this should be considered in their design.

This article proposes the use of an optimization technique to find the most adequate volume of rainwater reservoirs i.e. the optimal economical result measured by the Net Present Value (NPV): the Particle Swarm Optimization (PSO).

PSO is a population-based technique of stochastic nonlinear functions. Its use was inspired by social behavior in flocking birds or school of fishes (Boeringer, Weiner, 2004). It was used for this optimization process because of its flexibility and because it allows the inclusion of other variables that might interfere with the NPV calculation in any given future. This aspect expands the capacity of data processing without loss of efficiency of the algorithm.

In this study, PSO was used to size rainwater reservoirs in four case studies and the results obtained were compared with traditional methods that have been used for this purpose, verifying the improvement of the decision making process.

SIZING METHOD	Source	Annual rainfall	Monthly rainfall	Daily rainfall	Catchemnt area	Annual Demand	Montly Demand	Daily Demand	Roof Material
Annual Average	Gould; Nissen- Pettersen (1999)	x			x				
Brazilian Pratical Method	ABNT (2007)	x			x				
English Practical Method	ABNT (2007)	x			x				
German Practical Method	ABNT (2007)	x				x			
Australian Practical Method	ABNT (2007)		x			x			x
Rippl (Monthly data)	Thomas (2003); Campos (2004); ABNT (2007); Yruska (2010);		x				x		x
Rippl (Daily data)	Thomas (2003); Campos (2004); ABNT (2007); Yruska (2010);			x				x	x
Netuno@	Guisi et al(2007); Rocha (2009)			x					
Numerical Simulations	Fewkes (1999); Liao et al (2005); Liaw; Tsai (2004)			x	x			x	x
Weibull	Group Raindrops (2002); Simioni et al (2004)			x				x	

Table 1. Reservoir Sizing Methods and Inputs

2. Particle swarm optimization

The PSO algorithm is very similar to other evolutionary algorithms such as genetic algorithms (GA): the system takes a starting point with a population of variables and then research is done to find optimal solutions by the updating of generations. However, unlike the GA, there are no evolution operators, such as crossovers or mutations. Potential solutions, here called "particles", fly over the space of the problem, following the best particles (Particle Swarm Optimization, 2009).

An individual (particle) in communities as flocks or schools learns not only with the experiences that it had, but also with the experiences of the group to which it belongs. Thus, this technique tends to provide the best personal experience (position visited) and the best group experience.

The particles of PSO have a similar behavior. Through a simulation in a two-dimensional space, the velocity vector defines the displacement of the particle and another vector defines the position. The equations of these vectors are (Carrilho, 2007):

$$p_{k+1}^{i} = p_{k}^{i} + \upsilon_{k+1}^{i} \tag{1}$$

$$\upsilon_{k+1}^{i} = \omega\upsilon_{k}^{i} + C_1 rand_1\left(b_k^i - p_k^i\right) + C_2 rand_2\left(b_k^g - p_k^i\right) \quad (2)$$

Where:
k - an increase in pseudo-time unit;
$_{ki}$ - position of each particle i (candidate solutions) in time k (iteration);
$_{ki+1}$ - position of the particle i at time k +1;
b_{ki} - best position reached by the particle i at time k - best individual position;
b_{kg} - best position of the swarm at time k- is the best position reached by a particle used to guide the other particles in the swarm;
v_{ik} - speed of the particle i at time;
kv_{ik+1} - set speed of the particle i at time k +1;
rand1 and rand2 - independent random numbers (with uniform probability) between 0 and 1.
C1 and C2 - control information flow between the current swarm: If C2 > C1 – particle swarm will place confidence in the swarm, otherwise it puts confidence in itself. C1 and C2 are known as cognitive and social parameters respectively.
ω - inhere factor (or damping factor), which controls the impact of previous velocity of the particle on its current speed.
There are many different fields of application for PSO. Wang et al (2009) investigated the feasibility of the PSO algorithm to estimate the quality parameters of a water body. From the results obtained, it was observed that the proposed algorithm provides satisfactory results, either in relation to the genetic algorithm also developed for this purpose, or in the control data. The authors concluded that it is an important tool for calibrating water quality models. Another use of the PSO algorithm is for planning water supply systems (Yang; Zhai, 2009; Montalvo *et at*, 2010). Yang, Zhai (2009) compared the results obtained with the application of a genetic algorithm and PSO, demonstrating the flexibility of PSO, enabling the adaptability of the optimization of discrete and continuous variables.

3. Methods

The present study consists of theoretical research which involves the following steps: Survey of the methods that is regularly used in Brazil to size rainwater reservoirs, application of those methods in four case studies, simulation of sizing considering such methods, and the analysis of results; proposition of a tool to determine the volume based reservation.
The development of the PSO Tool involved:

a. Cost Estimation of each reservoir: The costs of the fiberglass tanks were obtained in building material stores; and a local construction company gave the estimated costs for the concrete tanks. From this, functions were created for the estimation of the costs of the tanks:

$$C = 0.1733V + 32.927 \text{ (Fiberglass tanks)} \quad (3)$$

$$C = 0.4672V + 12.791 \text{ (Concrete tanks)} \quad (4)$$

Where:
C – Cost of the tank (R$; US$1.00=R$1.66)
V – Volume of the tank (liters)

b. Modeling of the water price policy – functions for the estimation of the tariff were used, based on the values and classes of consumption by SANASA (Local water company). For commercial buildings, these functions are:

$$V \leq 10\ m^3 \qquad P = 32{,}50 \tag{5}$$

$$10 < V \leq 20\ m^3 \qquad P = 5{,}42V - 21{,}70 \tag{6}$$

$$20 < V \leq 30\ m^3 \qquad P = 8{,}63V - 85{,}90 \tag{7}$$

$$30 < V \leq 40\ m^3 \qquad P = 10{,}15V - 131{,}50 \tag{8}$$

$$40 < V \leq 50\ m^3 \qquad P = 11{,}82V - 198{,}30 \tag{9}$$

$$V > 50\ m^3 \qquad P = 14{,}25V - 319{,}80 \tag{10}$$

Where:
V – water consumption (m^3)
P - water tariff (R$; US$1.00 = R$1.66). The water tariff increase in the last 10 years was considered to calculate the average, maximum and minimum values for the simulations.
c. Determination of the Net Present Value (NPV) function
d. Use of PSO technique for optimizing the NPV function for each volume estimated.

The PSO based approach suggested in the present work aims to establish the optimal storage volume in a given rainwater harvesting building system, with regards to the maximization of the system's NPV. The system has two distinct modules: *simulation* and *optimization.*

The simulation module calculates the system's NPV over time, given a series of precipitations and tariff rates based on previous data. The simulation module's output is final NPV to be utilized as objective function.

The optimization module is based on a PSO in its version with global topology (*gbest* or *global Best PSO*). As previously described, the PSO is a search/optimization technique based on swarm intelligence, where the position of each particle in the search space represents a possible solution to the problem. In the suggested approach, the position of the particle in a given instant represents a possible storage volume for the system with the minimum volume (v_{min}) determined by the user and maximum (v_{max}) defined by the building occupation rate and the storage's maximum height. For the purposes of the experiment described here, the occupation has been set as 0,05% and the maximum height as 3m.

Initially, a 10 particle swarm was created and distributed uniformly in the search space on the interval [v_{min}, v_{max}]. Then, the *fitness* of each particle was calculated and for each one its *pbest* updated to its initial position. After that, *gbest* was defined as the position of the particle with the best *fitness* in the swarm. In the following iterations, the particles update their velocities according to the equation:

$$\upsilon_i(t+1) = \upsilon_i(t) + c_1 r_1(t)[y_i(t) - x_i(t)] + c_2 r_2(t)[y(t) - x_i(t)] \tag{11}$$

where $v_i(t)$ is the velocity of the particle in the instant t; $x_i(t)$ is the position of the particle i in the instant t, c_1 e c_2 are the acceleration constants that represent the social and cognitive components of learning and $r_1(t)$ e $r_2(t)$ are random values sampled from a uniform distribution U(0,1). These values have the objective of introducing a stochastic element in the algorithm. In the experiments, the learning factors c_1 e c_2 were defined as 2. This value was obtained empirically, establishing a satisfactory balance between search capability and depth and width.

The best position found by a particle i so far (i.e., *pbest*) is represented by y_i. As this is a problem of NPV optimization, *pbest* is calculated as follows:

$$y_i(t+1) = \begin{Bmatrix} y_i(t) & if & f\left(x_i(t+1)\right) \le f\left(y_i(t)\right) \\ x_i(t+1) & if & f\left(x_i(t+1)\right) > f\left(y_i(t)\right) \end{Bmatrix}$$

Where $f: R \to R$ is the *fitness* function, represented as the NPV as function of the system's storage volume. If in a given instant t a particle x finds a position that produces a better NPV than any previously found, its *pbest* is updated to the position of this particle in the instant t.

On the other hand, the development of the case studies involved the following activities:

a. Building selection: two aspects were considered in this selection - the building location should be close to the University of Campinas, where the rainfall data were captured and, and all design data should be readily available;
b. Rainwater demand estimation: rainwater was considered for supplying the following non-potable uses: toilet flushing; landscape irrigation and floor washing. Six scenarios of rainwater use were constructed: only for close-coupled toilet flushing (BD), only for landscape irrigation (R), only for floor washing (L) and four combinations of these scenarios: BD+R, BD+L, R+L and BD+R+L;
c. Rainfall volume estimation: the period for the analysis of rainfall data was from January 1971 through June 2009. Daily and monthly averages and maximum daily rainfall intensity, periods of drought and their frequencies were also analyzed;
d. Selection of the methods for the determination of the reservation volume: the following methods were chosen, based on the literature survey: Rippl (using daily and monthly rainfall data); Weibull, Netuno®, and the practical methods recommended in the Brazilian Standard: Azevedo Neto, English; Australian and German;
e. Sensitivity analysis based on different lifetimes and tariff value. There is no reference for lifetime of these components in the literature investigated. Thus, a period of 20 years was estimated for concrete tanks and 10 years for fiberglass tanks. For the water tariff, adjustments made by the local water company were considered with the starting point being the implementation of the Real (1994) by 2009;
f. Completion of the simulation, using the tool developed in this study.

An overview of the decision making process is shown from the results obtained, with a) the "conventional" sizing method and sensitivity analysis and b) with the results of the simulation. The sensitivity analysis provides a large number of options and outcomes to assess the volume and demand that will offer the greatest financial return, measured by the NPV of each situation.

The results were compared and analyzed in both the quantitative and qualitative aspects: optimal volume, initial investment, and payback of the investment, efficiency, lot occupation, and ease of use of the model including the input data. This analysis was made to verify the feasibility of using the PSO as a tool that can improve the decision making process in the design of the rainwater system, taking crucial factors for the decision process into account.

4. Results

4.1 Development of the PSO tool

Figure 1 shows the flowchart for the PSO tool. This flowchart was used to develop the RAIN TOOLBOX® software. As mentioned earlier, the PSO technique was chosen for this optimization process because of its flexibility, which allows the inclusion of other variables that may have an impact on the future NPV calculation, expanding the capacity of data processing, optimizing other variables besides the volume, such as the position of the reservoir, treatment required, etc., without losing efficiency of the algorithm. The PSO was shown to be a fast technique: the results were obtained in few seconds. The processing speed depends on both the number of particles (volume) and the number of interactions. This software allows choosing these variables.

Figure 2 shows the interface of the RAIN TOOLBOX® software. The first version is in Portuguese, the English version is being developed. In square 1, the following input data is required: Total area of the lot, catchment area, and rate of the lot will be used for the tank and the runoff coefficient. Square 2 contains the input data concerning to costs of implementation and maintenance (monthly, bimonthly, semi-annual and annual). The material of the reservoir, the consumer class (to define the water tariff), the daily demand of rainwater, and the maximum height of the reservoir are input in dialog box 3. Box 4 requires the rainfall data and the historical water tariff adjustment to be input. Lastly, in Box 5, the number of particles and interactions along with the minimum volume to be searched is typed.

4.2 Case studies

The rainfall data of the studied region is characterized by a dry season, with long periods of drought with an onset in April extending until August and a rainy season, from September to March. In the period studied (1971-2009), the rainiest month was January, with 272mm yearly average, followed by December (236mm/month) and February (193mm/month). Yearly, in the aforementioned period, the rainiest year was 1983 (2619mm), and driest was 1978 (811mm).

4.2.1 Case 1 – Residential building

This case features a two-story building with two bedrooms, one with a suite (room with a bathroom) and a restroom on the upper floor. Downstairs, it can be found a kitchen, a laundry room, the living room and a bathroom. The house was designed to accommodate 5 people.

The lot is 450 m^2, with the building covering 160 m^2. The building is covered with ceramic roof tiles and it has two roof surfaces. The yard is approximately 150 m^2. The predicted use of rainwater is for irrigation in the yard and toilet flushing. It was supposed that the yard is irrigated once a week, using 1 liter/ m^2, always from 06:00h to 08:00h.

It is estimated that each inhabitant flushes 6 times a day, 4 times being liquid and twice solid waste. Thus, we have a total of 30 instances of use, 20 with partial volume and 10 with total volume. Through previous observation, a daily distribution pattern was estimated.

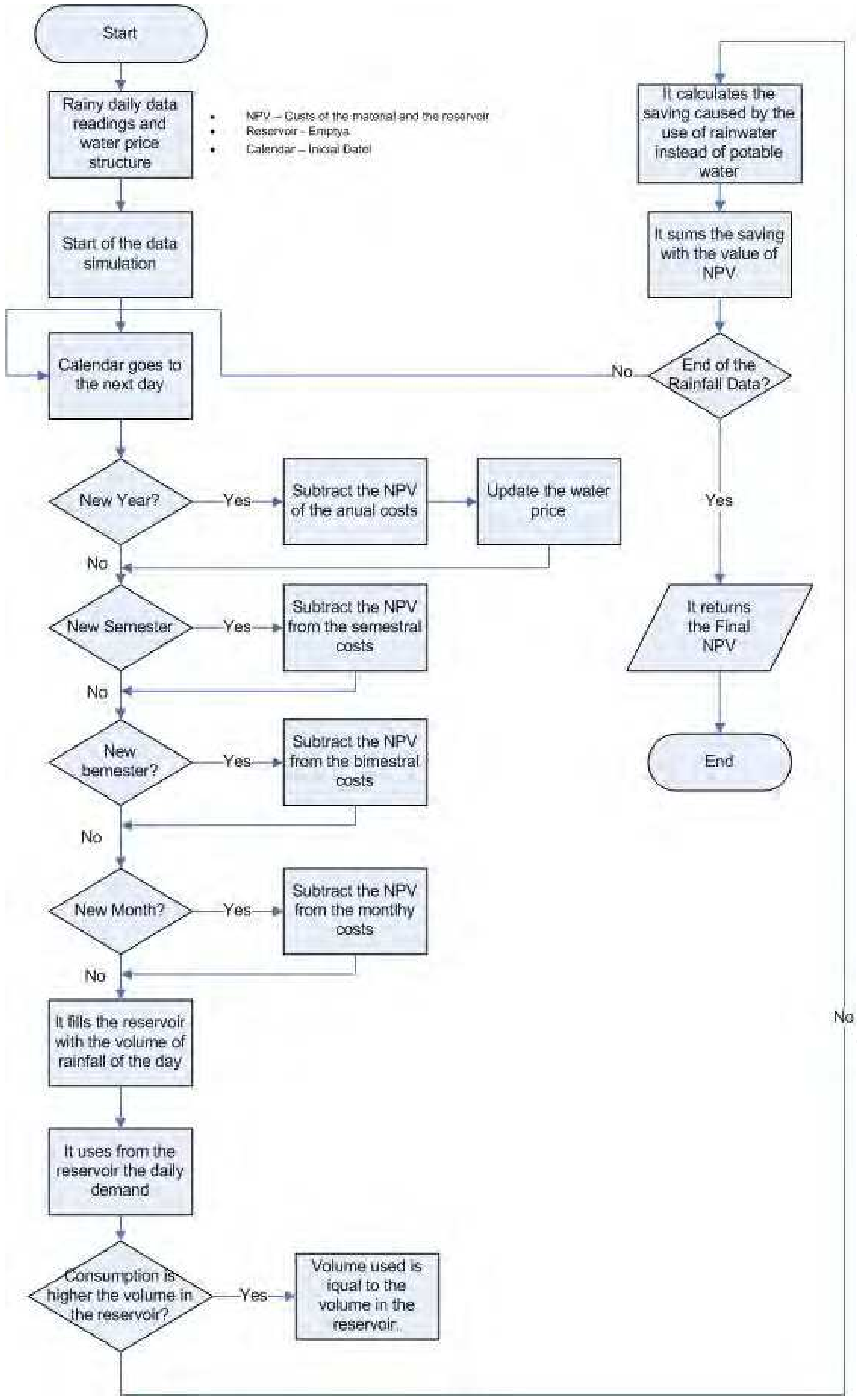


Fig. 1. Flowchart of PSO Tool.

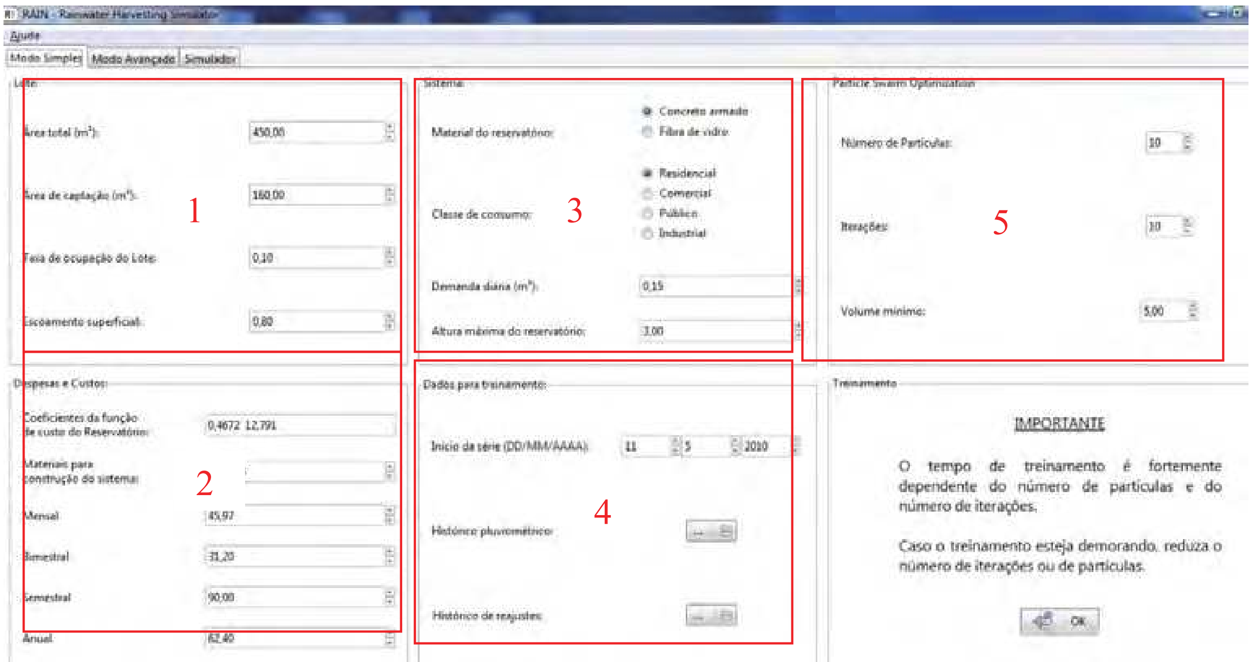


Fig. 2. Interface of Rain Toolbox® - in Portuguese.

The volume used by the toilets is 136 liters per day. Considering the 150 liters utilized in the yard's weekly irrigation, we have a total consumption of 1102 liters a week. Over 4 weeks (28 days), it was estimated that the demand for February is 4408 liters. For 31-day months a 1.107143 correction factor was applied and for 30-day months, a 1.071429 factor was applied, the result is, respectively, 4880.29 liters and 4722.86 liters.
Table 2 presents the reservation volumes obtained with the aforementioned methods.

Method	Reserved Volume (m^3)	Efficiency (%) determined according to Campos (2004)	Efficiency (%) determined by Netuno Software
Rippl Monthly	1,00	53	63
Rippl Daily	1,85	65	76
Practical Brazilian	33,55	100	100
Practical English	11,96	98	98
Practical German	3,45	76	85
Practical Australian	1,00	53	63
Weibull's Method	7,29	90	94
Netuno Software	3,50	76	85

Table 2. Reservation volumes obtained with standard methods e by Netuno Software – Case Study 1 – residential building

Analyzing the obtained results, a considerable discrepancy can be seen in the results from the Brazilian and English practical methods that yielded unexpectedly high values considering the magnitude of the building. The other methods yielded reasonable results, all feasibly applicable in a residence; nevertheless, with this information, it is still hard to determine which value to use. Thus, it was decided that a sensibility analysis of the results was to be made, with economic performance as criterion, which is also this work's main purpose. Each result presented in Table 3 was analyzed in terms of its economic efficiency of investment, according to the flowchart in Picture 2.
It's important to consider that the initial investment consists solely of the cost of storage, as all other costs are fixed, independently of the volume of the storage.
The costs were estimated for concrete and glass fiber storages. To estimate the cost of the storages, the previously explained model was utilized.
According to the estimated potable water demand (200 l/hab.day), the potable water economy would be 4.88 m^3, or U$10.84 monthly. However, as efficiency varies from volume to volume, this value will be proportional to its volume. The operating and maintenance cost was divided as follows: energy consumption – 30 working minutes per day: US$13.43/month; chlorine for purification - 4 g/m^3: US$0.03/month; cost of the analysis according to the Brazilian Standard: chlorine and pH – US$0.43/month (using test strips); turbidity – US$7.23/month; color – US$7.23/month; total coliforms: US$27.10 once a semester; fecal coliforms: US$27.10 once a semester; system maintenance: cleaning of the storage, gutters and pump – a domestic worker's daily wage – US$37.59/year; cleaning of the filter – half a domestic worker's daily wage – US$37.59/year.
The monthly cost, based on once a semester and twice a semester, proportionally accounted for US$49.86, which is higher than what would be saved in the best possible scenario for a household (with 100% efficiency, US$10.87 would be saved monthly). Thus it can be concluded that, economically, the investment would never return. However, there are other factors, economics aside, that should be taken into account, such as the real value of water and other environmental advantages.
So, even without economic advantages it is possible to choose a rainwater harvesting system due to its environmental advantages. The chosen system, however, must be the least economically disadvantageous. Table 3 presents the determined NPV values for each of the aforementioned methods, as function of maximum, minimum and average adjustments of the water tariff, which are respectively: 19.58%, 5.60% and 10.89%/year.
To apply the Rain Toolbox to case study 1, the height of the storage was limited to 3.00m and it was established that it must occupy 5% of the terrain's total area. The simulation, using 10 particles and 10 iterations, yielded 3.00 m^3 as result. For the concrete storage, the NPV was US$289.45 and for the fiberglass storage, it was US$5795.66. It was observed that the volume determined by the software was the same as the minimum posited (in this case 3.00 m^3 was utilized to supply the daily demand).
What had already been shown was confirmed by traditional analysis; the costs (construction, operation and maintenance) for the system in such residences are higher than the returns: independently of the utilized volume there will be loss, and the lower the volume, the lower the loss.

4.2.2 Case 2 – Institutional building

This case features an institutional building consisting of a group of classroom buildings of the Faculty of Civil Engineering, Architecture and Urbanism of the State University of Campinas.

Method	Volume (m^3)	Minimum Adjustment (5.60%)		Average Adjustment (10.89%)		Maximum Adjustment (19.58%)	
		20 years (concrete)	10 years (fiber)	20 years (concrete)	10 years (fiber)	20 years (concrete)	10 years (fiber)
Rippl Monthly	1.00	-2970.00	-2470.28	-2787.27	-2395.44	-2197.27	-2226.84
Rippl Daily	1.85	-31075.60	-2473.69	-2888.83	-2382.23	-2182.55	-2176.20
Practical Brazilian	33.55	-11576.60	-5485.16	-11240.10	-5344.46	-10153.50	-5027.49
Practical English	11.96	-5608.31	-3278.75	-5278.52	-3140.87	-4213.69	-2830.23
Practical German	3.45	-3450.34	-2559.99	-3194.59	-2453.06	-2368.80	-2212.16
Practical Australian	1.00	-2970.00	-2470.28	-2787.27	-2395.44	-2197.27	-2226.84
Weibull	7.29	-4386.74	-2855.34	-4083.87	-2728.72	-3105.96	-2443.44
Netuno	3.50	-3464.21	-2565.13	-3208.45	-2458.20	-2382.67	-2217.30

Table 3. NPV values (in US$) for each method and adjustment – Case Study 1 – residential building

It is comprised of three blocks, two already finalized and one still under construction. It has a total area of 1500 m², with four pavements. The total area for rainwater harvesting is 1222 m², covered by metallic roof tiles. Each pavement has two restrooms, each with 5 sinks and 5 close-coupled toilets and the men's restrooms have metallic gutter urinals. On ground level, there are two restrooms; the men's restroom has 5 close-coupled toilets, 5 sinks and 4 individual ceramic urinals. The women's restroom has 6 sinks and 4 close-coupled toilets.

The weekly average population at the time of this study was 2405 students, according to UNICAMP's administration. There was also a fixed population of 11. The irrigated area of the yard is 30 m².

A survey was made with regards to the frequency of use of the toilets, cleaning of the floor and yard irrigation. To estimate the demand, as in the residential building, the existence of double activation toilets was supposed. In this survey, 125 students were interviewed.

The average number of daily activations as surveyed was 0.90 per student. During 4 weeks (20 days), the demand for February was estimated. For 31-day months a 1.107143 correction factor was applied and for 30-day months, a 1.071429 factor was applied.

Using this data, different scenarios were made to analyze the use of pluvial water, according to Table 4.

Scenario	Projected Uses	Volume (m^3)		
		February	31 day Months	30 day Months
BD	Only flushing (double activation)	36.8	40.75	38.43
R	Only irrigation of the yard	0.86	0.96	0.93
L	Only floor washing	21.38	23.52	22.87
BD+R	Flushing (double activation) and irrigation of the yard	37.66	41.70	39.36
BD+L	Flushing (double activation) and floor washing	58.18	62.26	61.30
L+R	Irrigation of the yard and floor washing	22.24	24.47	23.80
BD+R+L	Flushing (double activation) and irrigation of the yard and floor washing	59.04	65.22	62.23

Table 4. Rainwater Demand for each scenario.

Scenarios	I	II	III	IV	V	VI	VII	VIII
BD	6.58	13.95	256.28	91.34	28.54	6.00	61.95	8.50
R	0.00	0.03			0.68	0.00	1.36	0.70
L	0.00	2.44			16.65	0.00	35.07	7.00
BD+R	8.48	13.35			29.22	8.00	61.61	8.50
BD+L	54.40	58.95			45.2	31.00	95.30	15.00
R+L	0.00	2.71			17.32	0.00	36.53	10.00
BD+R+L	61.25	70.08			45.87	32.00	96.72	16.00

NOTES:– Rippl Monthly; II – Rippl Daily Data; III – Azevedo Neto Pratical Method; IV – English Pratical Method; V – German Pratical Method; VI – Australian Pratical Method; VII – Weibull; VIII Netuno

Table 5. Reservation volumes obtained with the standard methods and Netuno software – Case Study 2 – institutional building.

As in case study 1, the economical evaluation was made by calculating the NPV of various methods, considering as cost only the construction of the storage.
In this case, there are various rainwater usage scenarios for the building. Hence, a series of variables have to be considered, such as the usage of the pluvial water and the utilized material (as in the previous case, 20 year lasting concrete and 10 year lasting fiber glass storages were analyzed). The same adjustments as in the previous case were utilized here as well: minimum, average and maximum in the period from 2001 to 2009, which were respectively: 5.59%, 10.88% and 19.63%. To illustrate, Fig.3 presents the NPV of fiberglass storage considering the minimum adjustment.

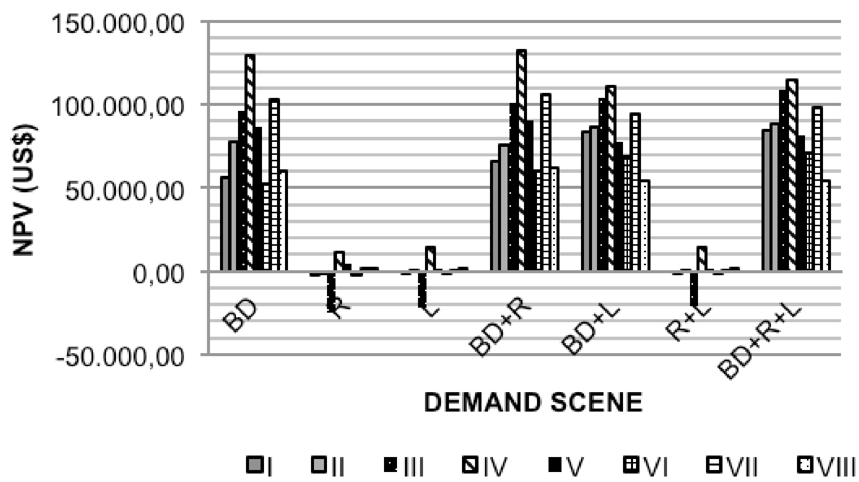


Fig. 3. Fiberglass storage NPV – minimum adjustment rate. Case study 2: Institutional Building.

It can be seen that the best NPV is yielded by the Brazilian practical method, utilizing fiberglass storages with cost higher than US$150,60.

Furthermore, scenarios with lower demand (R; L and R+L) are less favorable than others, nevertheless, if fiberglass is used, they show positive NPV for certain calculated volumes (practical Brazilian, English and German). The scenarios constituted for case study 2, independently of the method, were viable. This viability is largely due to high water taxes for this topology.

Another important factor is the large harvesting area of this building. This allows for a storage volume big enough to supply large demands, such as the ones estimated.

The result's analysis poses other questions such as:

- The Brazilian practical method usually yields large volumes. Despite this fact that when utilizing fiberglass, the results are economically interesting when compared to other methods.
- Results obtained using Weibull or Netuno methods are usually economically viable (NPV>0), independently of the demand scenario.
- The Practical English method yields high NPV values for the calculated storages, despite the material used, be it concrete or fiberglass.
- The lowest NPV values for volumes calculated were obtained using the Rippl Method, using either monthly or daily data.

The volume that yielded the highest NPV was calculated using the practical English method, for flushing and yard irrigation (BD+R), with 91.34 m^3, with value higher than US$180,723, for the average adjustment rate.

If fiberglass storage were used, the highest NPV would be obtained with the volume calculated using the practical English Method in a scenario of demand, considering the average adjustment rate, approximately US$180,723.

As input to the simulation with Rain Toolbox, the total area is 1500 m^2 and the harvesting area is 1500 m^2. The storage height was limited to 3.00 m and its area to 5% of the total area. The simulation with 10 particles with 10 iterations yielded the results seen in Table 6.

Scenario	Concrete storage		Glass fiber storage	
	Volume (m^3)	NPV (US$)	Volume (m^3)	NPV (US$)
BD	161.24	223616.46	160.25	55835.69
L	1.00	6014.72	1.00	-1246.03
R	83.66	82617.96	7302	18840.31
BD+L	170.28	235312.23	16980	58903.62
BD+R	298.24	499238.69	295.38	128134.95
L+R	92.55	90275.09	75.62	20850.07
BD+L+R	303.39	511214.44	303.32	131277.15

Table 6. Reservation volumes obtained with Rain Toolbox. Case study 2 – Institutional building.

Analyzing the obtained results, it is possible to choose the highest NPV scenario, if the budget is large enough. Moreover, it can be seen that, economically, concrete storages are more advantageous than fiberglass storages.

Also, in scenario L, the financial return is very small or non-existent (if fiber glass is used).

The values for the storages calculated are relatively larger than the ones yielded by traditional methods. However, the utilization of these volumes can maximize financial return, making the implementation of rainwater harvesting systems more attractive.

4.2.3 Case 3 – Office building

An office building with 56 business rooms divided equally on two floors was selected for this case study. Each room has one close-coupled toilet and one washbasin. This building has not been built. The area in question is 1,431.40m², the garden is 675.65 m², the impermeable area is 2,942.15 m² and the internal area is about 443.45 m².

The estimated population is 757 people. The demand of rainwater was estimated based on the literature. The estimated total number of toilet flushes per person per day is 3 (2 flushes with approximately 3.5 L/f and 1 flush with about 7 L/f). An indicator of 1 L/m² was considered for landscape irrigation and for floor washing. The frequency of these activities is twice a week and once a week, respectively (Campos *et al*. 2003).

Based on these hypotheses, the rainwater demand for February was estimated as the demand pattern. For months with 31 and 30 days, correction factors of 1.107143 and 1.071429, respectively, were used. Table 7 shows de results. Table 8 shows the volumes obtained with use of those methods.

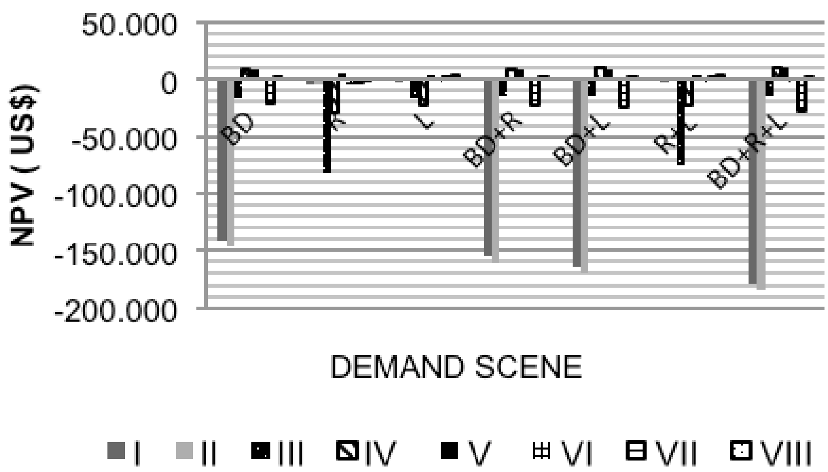
Scenario	Projected Uses	Volume (m^3)		
		February	31 day Months	30 day Months
BD	Only flushing (double activation)	205,90	227,96	220,61
R	Only irrigation of the yard	8,12	8,99	8,70
L	Only floor washing	13,54	14,99	14,51
BD+R	Flushing (double activation) and irrigation of the yard	214,02	236,95	229,31
BD+L	Flushing (double activation) and floor washing	219,45	242,97	235,12
L+R	Irrigation of the yard and floor washing	21,66	23,98	23,21
BD+R+L	Flushing (double activation) and irrigation of the yard and floor washing	227,56	251,94	243,82

Table 7. Rainwater demand for different scenarios of use – case study 3 – office building

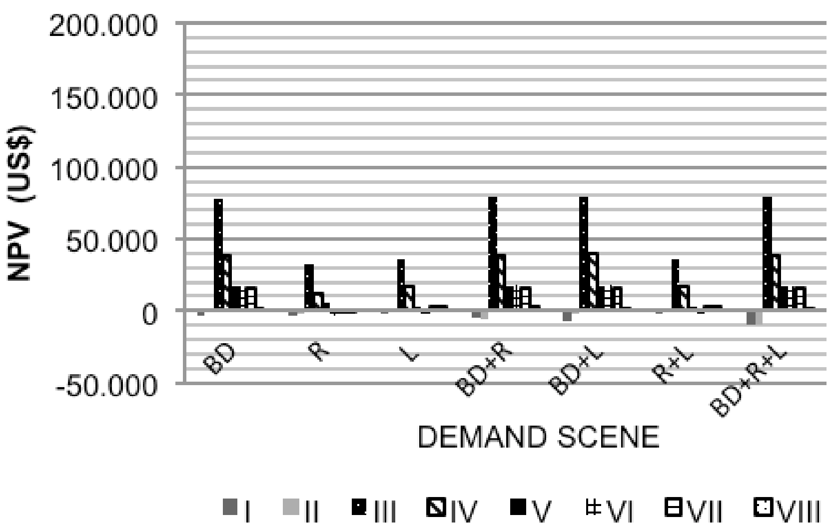
Rainwater demand scenarios	Volume of the reservoir (m³)							
	I	II	III	IV	V	VI	VII	VIII
BD	1038.6	1087.3	300.2	107.0	115.6	186.0	334.8	10.5
R	0.0	0.5			6.3	0.0	13.2	4.0
L	0.0	1.1			10.6	0.0	21.9	5.0
BD+R	1118.4	1167.8			115.6	195.0	348.0	10.5
BD+L	1171.6	1222.1			115.6	200.0	356.6	10.0
L+R	0.0	2.1			10.6	0.0	21.9	5.0
BD+R+L	1251.3	1305.9			115.6	209.0	369.8	10.5

Table 8. Reservation volumes obtained with the standard methods and Netuno software – Case Study 3 – Office Building.

The NPV was determined for 6 situations: lifetime of 10 years (fiberglass tanks) and 20 years (concrete Tanks) and 3 readjustment rates of water tariff, based on historical data: minimum, average and maximum. Figure 4 shows the results for the average readjustment rate.



Concrete Tanks



Fiberglass Tanks

Note: US$ 1.00 = R$ 1.66 (02/18/2011)

Fig. 4. NPV for concrete/fiberglass tanks - average readjustment

All input data were shown earlier. Additionally, the following data was considered: Height of 3,00 m for the reservoir, percentage of the lot will be occupied by the reservoir: 5% of the total area of the lot and simulation with 10 particles and 10 interactions. Table 9 shows the results.
The commercial opportunities of the use of the simulation are related to investments that can be considered infeasible or not so feasible, which could discourage investments in rainwater harvesting systems.

Raiwater demand scenarios	Concrete Tanks		Fiberglass Tanks	
	Vol(m^3)	NPV(US$)	Vol(m^3)	NPV (US$)
BD	101.4	1351650.72	101.4	329909.77
L	5.0	14560.97	5.0	-1705.45
R	51.8	37620.16	46.2	4338.77
BD+L	101.4	1354093.47	101.4	329909.77
BD+R	101.4	1389173. 78	101.4	337771.93
L+R	51.9	37620.15	45.2	4338.87
BD+L+R	101.4	1389173.78	101.4	337771.93

Table 9. Volumes and NPV using Rain Toolbox®

Besides that, the method proposed a factor that was not considered elsewhere. Economic variables are also important to stimulate the use of alternative sources of water, mainly for non-potable uses.

4.2.4 Case 4 – Commercial building (industrial plant)

The fourth and last case is a building in an industrial complex in the city of Paulinia, located only 5 km from the other cases analyzed in this work. This building is comprised of 4 pavements, in the first there is a kitchen and a refectory, in the other the administrative offices of the complex can be found.
Each pavement has two men's and two women's restrooms. On the ground level, aside from the four restrooms, there are two changing rooms, one for each gender. The kitchen has a capacity for 250 meals/day and a total of 180 workers.
The covered area is 291.40 m². The building has a 410.55 m² garden and an impermeable area of 677.13 m².
Similarly to cases 2 and 3, rainwater demand scenarios were made (BD, R, L, BD+R, BD+L; L+R e BD+L+R). Taking into account that the building was not constructed yet, the consumption data and usage of the sanitary facilities of the consulted bibliography were estimated.
Thus, 3 flushes/day*person were projected (Tomaz, 2000), 2 with partial volume and 1 with the total volume. One L/m² for the garden's irrigation was estimated, three times a week; and 1 L/m² to wash the floors, once a week. Considering 4 weeks (28 days), the demand for February was estimated. For 31-day months a 1.107143 correction factor was applied and for 30-day months, a 1.071429 factor was applied. Table 10 shows the results yielded.
The reservation volumes determined by the different methods are presented in Table 11.

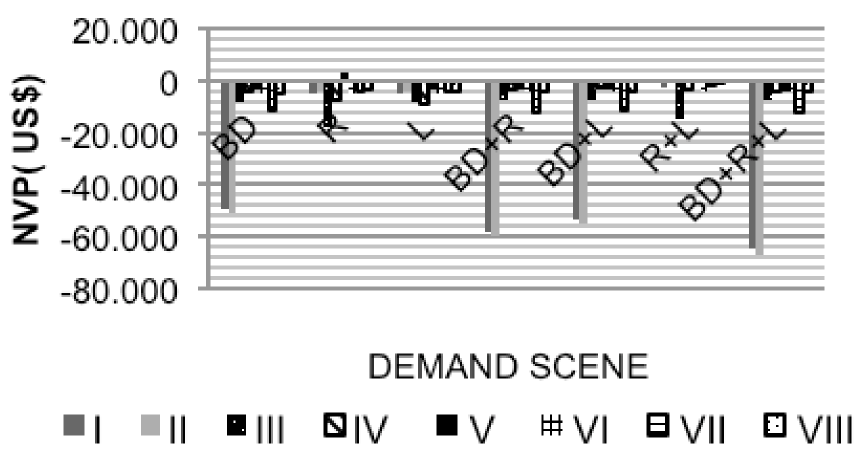
Scenario	Volume (m³)		
	February	31 day Months	30 day Months
BD	48.96	54.20	52.46
R	4,96	5.45	5.28
L	2.71	3.00	2.90
BD+R	53.89	59.66	57.74
BD+L	51.69	57.20	55.36
L+R	7.63	8.45	8.18
BD+R+L	56.59	62.66	60.64

Table 10. Rainwater demand for the considered scenarios

Rainwater demand scenarios	Volume of the reservoir (m³)							
	I	II	III	IV	V	VI	VII	VIII
BD	295.76	308.15			22.22	5.00	78.75	5.00
R	0.00	0.70			3.21	0.00	7.92	4.50
L	0.00	0.22			1.77	0.00	4.35	4.00
BD+R	351.56	364.13	61.11	21.78	22.22	7.00	86.61	5.00
BD+L	325.09	337.88			22.22	5.00	83.04	5.00
L+R	1.02	2.67			4.95	0.00	12.27	4.50
BD+L+R	384,50	398.44			22.22	7.00	90.96	5.00

Table 11. Rainwater demand for different scenarios of use – case study 4 – office building industrial plant

Similarly to the previous cases, the economical analysis was carried out by calculating each scenario's NPV. The previously used adjustment rates are used here as well. Fig. 5 presents the results yielded using the average adjustment rate.



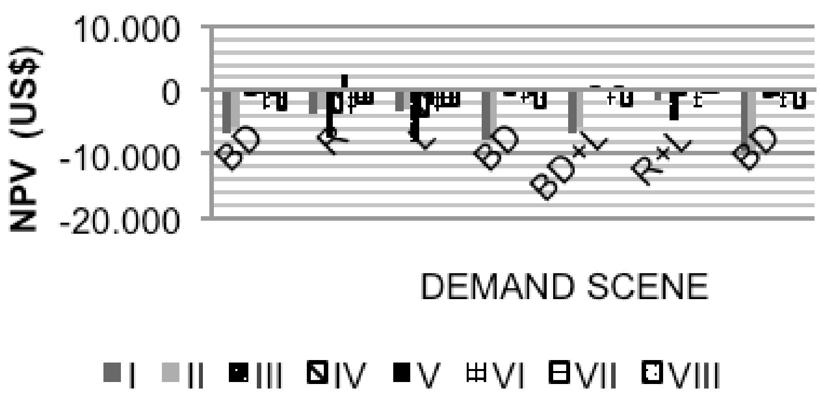


Fig. 5. NPV for concrete/fiberglass tanks - average readjustment

Even considering the maximum adjustment rate of the historical series, most scenarios remain unviable, with negative NPV.
In the case of concrete storages, only the volume determined using the Practical German Method for the L scenario and the Practical Brazilian Method for BD+R, BD+L and BD+R+L yielded positive NPV. The highest value, however, was calculated using the volume found with the Practical German Method for the R scenario (US$7,721.08).
For fiberglass storages, aside from the aforementioned scenarios, the NPV positive values were yielded by the Rippl method be it with daily or monthly data, for the BD, BD+R, BD+L and BD+R+L. The highest NPV was found using the volume determined with the Rippl method, with daily data for the BD+L scenario, which was US$7,687.34.
Given the results, for case study 4 only the irrigation scenario would be viable (NPV>0) if the storage used had 3.21 m^3 of volume, value yielded by the Practical German Method.
Furthermore, considering average and minimum adjustment scenarios, which are more realistic, this case has a positive NPV.
This is unviable largely due to the small harvesting area in relation to the relatively high demand, which calls for larger volumes.
Furthermore, not only in this case but also in others, even if the largest NPV volumes were to be utilized, one cannot be sure that it would yield the best results.
Considering this and maintaining the same input data as in the previous case studies (maximum storage height of 3.00m, maximum area of 5% of the total land area and the simulation with 10 particles and 10 iterations), the following NPV values were calculated for each volume and presented in Table 12.

Scenario	Concrete storage		Glass fiber storage	
	Volume (m^3)	NPV (US$)	Volume (m^3)	NPV (US$)
BD	163.15	137349,4	52.99	24293,02
L	5.00	12019,8	5.00	-2405,91
R	5.00	12019,8	5.00	-2405,91
BD+L	163.15	143905	49.02	25368,73
BD+R	160.40	146723,1	45,13	25943,1
L+R	5.00	12019,8	5,00	-2405,91
BD+L+R	131.43	151674,7	44.99	26586,67

Table 12. Volumes and NPV using Rain Toolbox®

4.2.5 Comparative analysis

Tables 13 and 14 show the best results yielded by the sensibility analysis and the model proposed in this work, respectively for concrete and fiberglass storages.

Case study		Best result (scenario)	
		Sensibility Analysis	Rain Toolbox
1	Volume (m^3)	1.00	3.00
	NPV (US$)	-2970	-891.86
2	Volume (m^3)	91.3 (BD+R)	303.3 (BD+R+L)
	NPV (US$)	191775.02(BD+R)	511214.4 (BD+R+L)
3	Volume (m^3)	107.00 (R)	101.4 (BD+R+L)
	NPV (US$)	10678.55 (R)	1337301 (BD+R+L)
4	Volume (m^3)	3.21 (R)	131.4 (BD+R+L)
	NPV (US$)	3091.67 (R)	151674.70 (BD+R+L)

Table 13. Best results yielded by sensibility analysis and by Rain Toolbox - concrete storage.

Case Study		Best Result (scenario)	
		Sensibility Analysis	Rain Toolbox
1	Volume (m^3)	1.00	3.00
	NPV (US$)	-2470,28	-5795,67
2	Volume (m^3)	91.3 (BD+R+L)	303.3 (BD+R+L)
	NPV (US$)	157052.76 (BD+R+L)	131277.20 (BD+R+L)
3	Volume (m^3)	300.2 (BD)	101.4 (BD+R+L)
	NPV (US$)	79475.76 (BD)	339806.70 (BD+R+L)
4	Volume (m^3)	3.24 (R)	45.00 (BD+R+L)
	NPV (US$)	2534.17 (R)	26586.67 (BD+R+L)

Table 14. Best results yielded by sensibility analysis and by Rain Toolbox - concrete storage.

It can be seen that the use of economic criteria to size storages is an interesting alternative that solves the lack of criteria in determining the volume. Moreover, the use of sensibility analysis, though extremely laborious, yields economically satisfactory results. The use of PSO as a way to incorporate was also very effective, providing the decision maker another investment opportunity, seeking the best possible return.

Analyzing with software, it is observed that the gain from the use of the volumes determined by the proposed method for cases 3 and 4 is evident: not only was the highest NPV found, but the demand also was completely supplied. For cases 1 and 2, the yield by the sensibility analysis is larger than the ones yielded by the proposed method. This is due to the fact that different adjustment factors were used in each method. Even though the minimum, average and maximum values were used in the sensibility analysis, the results selected for comparative analysis were the ones corresponding to an average adjustment rate.

Some of the volumes determined using the Rain Toolbox can be considered high, but they are limited by available land, never occupying more than 5% of its total free area.

With this method of sizing reservoirs, it is possible to make investments in rainwater harvesting systems more attractive, as there is a possibility of financial return.

This is only one way to think about the sizing of these system's reservoirs. Evidently a hydrological analysis of the system must be performed, but it has to be noted that the system is part of a building, increasing its costs, and they must frequently be viable not only environmentally, but also economically and financially.

The method proposed also seeks to solve a common problem in other such methods, which is the incompatibility of the storage's volume and land availability. This is the case especially in urban areas, where there this is a problem with other methods, which take the proposed method into account, fixing a maximum percentage of the land's area for the storage to occupy. The development of the computational tool contributes to facilitate the implantation of these concepts, incorporating a more fitting sizing method, considering the aforementioned aspects.

5. Conclusion

This article's main objective was to evaluate the incorporation of economical factors and land occupation for the dimensioning of rainwater harvesting system storages.
For this purpose, two methods were analyzed: firstly, sensibility analysis of various demand, water tariff adjustment and storage service life scenarios. Secondly the use of PSO as optimization technique of the NPV function, yielding the volume that gives the highest NPV value, considering a maximum limit of land occupation.
Both methods are viable to determine the reservation volume, however PSO revealed itself as the more interesting alternative, since the developed software will enable the decision of whether the system should be implemented and the optimal volume and it can reveal previously dismissed opportunities.
This technique's biggest advantage is its flexibility. It is possible, at certain moments, to introduce new variables to help determine the storage's volume, and it works well with one or multiple variables. Other limiting factors could be included in proposed method, such as initial investment, which allows this software to yield a volume compatible with the investor's budget. On the other hand, it is considered that future studies may clarify aspects not touched upon in this work, such as the inclusion of further parameters that can interfere with the decision-making and the behavior of the system in different rainfall patterns, as enhancements.
It is our hope that this work will effectively contribute to the enhancement of storages, increasing the number of these systems, improving conservation of water in buildings and helping urban draining.

6. Abbreviation list

GA – Genetic Algorithms
Gbest – Global best
NPV – Net Present Value
Pbest – personal best
PSO – Particle Swarm Optimization

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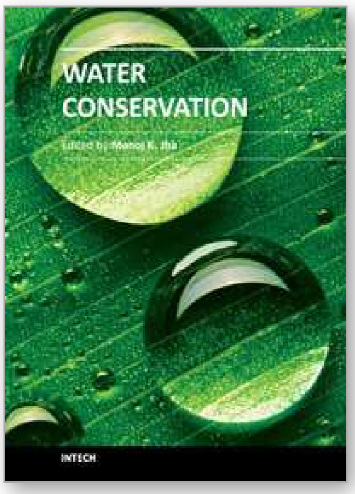

Water Conservation

Edited by Dr. Manoj Jha

ISBN 978-953-307-960-8

Hard cover, 152 pages

Publisher InTech

Published online 09, December, 2011

Published in print edition December, 2011

Water is an essential and basic human need for urban, industrial and agricultural use. While an abundance of fresh water resources is available, its uneven distribution around the globe creates challenges for sustainable use of this resource. Water conservation refers to an efficient and optimal use as well as protection of valuable water resources and this book focuses on some commonly used tools and techniques such as rainwater harvesting, water reuse and recycling, cooling water recycling, irrigation techniques such as drip irrigation, agricultural management practices, groundwater management, and water conservation incentives.

How to reference

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Marina Sangoi de Oliveira Ilha and Marcus André Siqueira Campos (2011). Determination of the Storage Volume in Rainwater Harvesting Building Systems: Incorporation of Economic Variable, Water Conservation, Dr. Manoj Jha (Ed.), ISBN: 978-953-307-960-8, InTech, Available from: http://www.intechopen.com/books/water-conservation/determination-of-the-storage-volume-in-rainwater-harvesting-building-systems-incorporation-of-econom

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